Addemdum to: "The Mathematical Structure of Quantum Superspace as a Consequence of Time Asymmetry".

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In this paper we improve the results of sec. VI of paper [M. Castagnino, Phys. Rev. D **57**, 750 (1998)] by considering that the main source of entropy production are the photospheres of the stars.

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I. A ROUGH COINCIDENCE BECOMES MORE PRECISE.

In paper [1] one of us reported a rough coincidence between the time where the minimum of the entropy gap $\Delta S = S_{act} - S_{\max}$ [2], takes place and the time where all the stars will exhaust their fuel. The time where the minimum of ΔS is located was:

$$t_{cr} \approx t_0 \left(\frac{2}{3} \frac{\omega_1}{T_0} \frac{t_{NR}}{t_0} \right)^3 \tag{1}$$

The following numerical values were chosen: $\omega_1 = T_{NR}$, the temperature of the nuclear reactions within the stars (that was considered as the main source of entropy), $t_{NR} = \gamma^{-1}$ the characteristic time of these nuclear reactions, t_0 the age of the universe, and T_0, the cosmic micro-wave background temperature, and making some approximations the rough coincidence was obtained.

Now we have reconsider the problem and conclude that, even if nuclear reactions within the stars are a source of entropy, the parameters T_{NR} and t_{NR} are not the good ones to define the behavior of the term $e^{-\gamma t/2}\rho_1$ of equation (100) of paper [1], since they do not correspond to the main unstable system that we must consider. In fact the main production of entropy in a star is not located in its core, where the temperature is almost constant (and equal to T_{NR}), but in the photosphere where the star radiates. The energy radiated from the surface of the star is produced in the interior by fusion of light nuclei into heavier nuclei. Most stellar structures are essentially static, so the power radiated is supplied at the same rate by these exothermic nuclear reactions that take place near the center of the star [3]. We can decompose the whole star in two branch systems [2], as explained in section VII of paper [1], where a chain of branch systems was introduced. We have two branch systems to study: the core and the photosphere. The core gives energy to the photosphere and in turn the photosphere diffuses this energy to the surroundings of the star, namely in the bath of microwave radiation at temperature T_0 . In this way, we have two sources of entropy production: the radiation of energy at the surface of the star and the change of composition inside the star (as time passes we have more helium and less hydrogen). Since the core of a star is near thermodynamic equilibrium, we neglect the second and we concentrate on the first: the radiation from the surface of the star (related with the difference between the star and the background temperatures). So the temperature of the photosphere and not the one of the core must be introduced in our formula. Thus it is better to consider the photosphere as the unstable system that defines the term $e^{-\gamma t/2}\rho_1$ of equation (100) [1]. So we must change T_{NR} and t_{NR} by T_P, the temperature of the photosphere and t_S the characteristic lifetime of the star. Then we must change eq. (1) to:

$$t_{cr} \approx t_0 \left(\frac{2}{3} \frac{T_P}{T_0} \frac{t_S}{t_0} \right)^3 \tag{2}$$

As the 90% of the stars are dwarfs with photosphere temperature $T_P = 10^3 K$ [4] and the characteristic lifetime $t_S = 10^9$ [5] if we take these values we reach again to.

$$t_{cr} \preceq 10^4 t_0 \tag{3}$$

but now with no approximation. The order of magnitude of t_{cr} is a realistic one. In fact, $10^4 t_0 \approx 1.5 \times 10^{14} years$ after the big-bang the conventional star formation will end [6] and it is also considered that all the stars will exhaust their fuel [7] so it is reasonable that this time would be of the same order than the one where the entropy gap stops its decreasing and begins to grow [8]. So the rough coincidence it is now a precise order of magnitude coincidence and therefore the comprehension of paper [1] is improved.

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[1] M. Castagnino. Phys. Rev. D **57** (2), 750, 1998.
[2] P. C. W. Davies, in *Physical Origin of Time Asymmetry*, edited by J.J.Halliwell et al. (Cambridge University Press,Cambridge, England, 1994).
[3] D. Clayton, *Principles of Stellar Evolution and Nucleosynthesis* (Mc Graw Hill, New York, 1968).
[4] W. W. Wiess, A. Beglin (eds.), *Inside the stars,* IAU colloquium 137, Astronomical Society of the Pacific, Conference Series **40,** 1993.
[5] A. Unsöld, *Der neue kosmos (*Springer Verlag, Berlin, 1974).
[6] F. Adams, G. Laughlin, Rev. Mod. Phys., **69**, 337, 1997.
[7] D. A. Dicus, J.R. Letaw, D. C.Teplitz, V. L., Teplitz, *Effect of proton decay on the cosmological future,* Astrophysical Jour., **252,** 1, 1982.
[8] H. Reeves, *The growth of complexity in an expanding universe,* in The Anthropic Principle, F. Bertola, U. Curi, eds. (Cambridge Univ. Press, Cambridge 1993).